Comments on and Discussion of
The Liquid Carbon Challenge: Evolving Views on Transportation Fuels and Climate

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March 2015

In *The Liquid Carbon Challenge: Evolving Views on Transportation Fuels and Climate*, DeCicco (2015) raised a few issues regarding evaluation of biofuel greenhouse gas (GHG) emission effects. He asserted that biofuel analyses thus far were done with "system boundary misspecification, flawed carbon cycle representation, and use of a static framework to analyze dynamic systems." We provide here comments on some of the issues raised by DeCicco.

Greenhouse Gas Analytic Approaches

DeCicco provided a review of four individual GHG assessment approaches—fuel-cycle analysis (FCA), terrestrial resource assessment (TRA), GHG inventory accounting, and integrated assessment modeling (IAM)—to address GHG emissions in the context of biomass as a resource for biofuels. These assessment approaches have been developed for very different purposes. FCA, or life-cycle analysis (LCA) in general, was historically developed to address omissions in emission coverage from vehicle tailpipes to upstream fuel production by including the entire fuel supply chain, including fuel combustion. This full fuel-cycle coverage has been especially important as transportation-sector GHG policies have evolved in the past 25 years to address new fuels (such as electricity, hydrogen, and biofuels) as well as new vehicle systems. Without FCA, GHG emissions from fuel production for certain vehicle/fuel systems (such as electric drive technologies fueled with electricity and hydrogen) are omitted, as these systems' emission burdens are simply shifted from vehicle operation to fuel production (such as electric drive technologies fueled with electricity and hydrogen). Further, regulatory agencies have recognized the need to reduce GHG intensities of fuels, as well as to reduce fuel use via vehicle efficiency improvements, to realize significant reductions in transportation GHG emissions (CARB 2009; EC 2009; USEPA 2010). With the advances in FCA over the past seven years in key areas such as LCA system boundary, treatment of co-products, and inclusion of indirect effects (such as changes in land use for biofuel production), FCA has become a helpful tool for developing policies to reduce the GHG intensity of transportation fuels.

The TRA method has been used to assess carbon mitigation in general and bioenergy potentials and their GHG reductions in particular. It examines carbon sinks and sources of terrestrial resources by considering the dynamics of carbon-stock changes in terrestrial systems over time. TRA results have been helpful in identifying opportunities for using global biological systems to manage global GHG emissions. However, as DeCicco acknowledged, they have not been used to evaluate biofuel systems or to develop GHG reduction policies.

The GHG inventory accounting approach was adopted by the United Nations Framework Convention for Climate Change (UNFCCC 2006) for nations to develop GHG inventories. The UNFCCC protocol was adopted by the Intergovernmental Panel on Climate Change (IPCC 2006) for developing GHG emission assessments. In developing GHG emission assessments related to bioenergy production, the UNFCCC maintained that CO_2 emissions from biomass combustion (biogenic CO_2 emissions) should be assumed to be zero. This assumption was intended to avoid accounting for biogenic CO_2 emissions without considering CO_2 uptake during biomass growth. In fact, this so-called carbon neutrality assumption for biomass combustion was introduced precisely for the purpose of avoiding double-counting of biogenic CO_2 emissions. More discussion on this topic is presented in a later section of this commentary. The GHG inventory accounting itself is not a GHG analytic method and has not been used for GHG policy development. Rather, it is aimed at providing nations and regulatory bodies with information on the relative amounts of GHG emissions by sector.

There are many different kinds of IAM models, and they can be applied at scales ranging from local to global. Wicke et al. (2014) provide a characterization of the strengths and limitations of four categories of models, and they differentiate between IAM models and computable general equilibrium (CGE) models. However, DeCicco appears to cover only the aggregate IAMs. Therefore, we will discuss below only the aggregated models, which often have a CGE structure, and which we call IAM (CGE) here. The IAM (CGE) approach provides guidance to identify key sources for GHG reduction across different economic sectors and in different regions by linking sectors and regions. While IAM (CGE) can help assess effects of GHG reduction policies such as global-scale, all-sector carbon tax policies, this approach has not been used to develop GHG policies. The IAM (CGE) approach is based heavily on linkages among economic sectors that are often based on historical data (some of which are out of date), and great uncertainties exist in predicting future economic linkages (especially for emerging economic sectors that did not exist in the past). Because of the complexity of IAM (CGE) models, they are often not transparent to model users and policy makers in terms of how results are affected by which key parameters. This shortcoming weakens the application of IAM (CGE) to policy development. While DeCicco advocated this approach for energy systems, he did not offer suggestions on how IAM (CGE) could be used to design policies to pursue GHG reduction.

While verification of the impacts of FCA-based policies is challenging, FCA, mostly based on project-level data, at least offers understanding and insights regarding carbon sinks and sources and may result in eventual verification. On the other hand, it may be challenging to verify estimated policy impacts from IAM (CGE)-based models since they are built with direct and indirect linkages among different economic sectors and global regions.

FCA results are often normalized to simple numbers such as grams of GHG emissions per MJ of fuel for the purpose of developing specific regulations. This normalization is not an inherent feature of FCA. In fact, such normalization usually requires an arbitrary biofuel program lifetime.

For example, when normalizing biofuel GHG emissions to a g/MJ basis, the arbitrarily assumed lifetimes of biofuel programs—20 years (EU), 30 years (California Air Resources Board), and 30 years (USEPA)—may underestimate the true reductions achieved, since no government agency is suggesting that a biofuel program would last for that short a period. The Brazilian sugarcane ethanol program and the U.S. ethanol program have already lasted much longer than the arbitrary biofuel lifetimes assumed by the regulatory agencies. DeCicco was confused between the FCA method and the need for regulations to have a simple GHG metric for fuel carbon intensity.

Over the past eight years, the introduction of biofuel land use changes into biofuel LCAs has helped integrate the TRA method into the biofuel FCA method. For example, soil carbon changes due to land use changes are now often accounted for in biofuel FCAs. These analyses (e.g., Kwon et al. 2013) take into account prior land use, although DeCicco incorrectly pointed out that prior land use is not considered in the reference system boundary for LCA. Needless to say, further advancement and improvements of the integration of the two approaches (and other approaches) are needed in order for FCA to provide comprehensive results for transportation fuel policy development (see Wicke et al. 2014).

Carbon Neutrality Assumption for Bioenergy

The UNFCCC, in its GHG accounting protocol, directs nations that submit GHG emissions inventories to assign a value of zero to CO_2 emissions from biomass combustion (UNFCCC 2006). Further, the UNFCCC maintains that nations must account for carbon stock loss (reported as CO_2 emissions) due to biomass harvest in their reporting of emissions in the Land Use, Land-Use Change and Forestry (LULUCF) sector. UNFCCC aims to avoid double-counting of carbon stock loss from biomass harvest and combustion by maintaining this reporting convention. If nations reported *both* carbon stock loss from biomass harvest *and* carbon emissions from combusting that biomass, they would double-count emissions from using this biomass as an energy source. Searchinger et al. (2009) and Haberl et al. (2012) (as cited by DeCicco) critiqued this UNFCCC carbon accounting convention, which Searchinger and others termed "double accounting error." But, to be precise, they should have used a different term such as "omission of biomass combustion CO_2 emissions." It was exactly "double-counting" that the UNFCCC intended to avoid in its protocol.

International trade in bioenergy creates an opportunity for this UNFCCC convention to result in potential omission of CO_2 emissions from bioenergy use. Individual nations subject to Annex I report their annual GHG emissions; non-Annex I nations do not. Thus, if bioenergy (including biofuels) is produced in non-Annex I countries but exported to Annex I countries for use, CO_2 emissions from biomass stock loss in non-Annex I nations are not reported while bioenergy combustion in Annex I countries is assigned zero CO_2 emissions, resulting in a net omission of CO_2 emissions. Also, even though GHG emissions are required to be reported for all the sectors, including LULUCF, there is no guarantee that individual nations will always cover this sector and cover it thoroughly. Some researchers are concerned that there would be an omission or partial omission of GHG emissions related to bioenergy within a nation because of the cross-sector nature of bioenergy production and consumption. Global accounting and thorough sectorial accounting should be implemented to avoid such omissions under the UNFCCC.

As an LCA tool, GREET (and many other models) covers many sectors along a fuel supply chain. Ten years ago, Argonne became concerned that assigning zero CO_2 emissions to biofuel combustion might create a belief among GREET users that biomass combustion did not, in fact, emit CO_2. As a result, Argonne changed the GREET model to explicitly assign CO_2 emissions to biomass combustion. Meanwhile, Argonne assigned a CO_2 uptake credit to biomass growth. This approach to separating CO_2 emissions and uptake in biofuel evaluation is discussed by Wang et al. (2012) (see Figure 4 in particular). The separation of emissions and uptake was intended to maintain transparency, so that GREET users could always question how much, if any, CO_2 uptake credit should be assigned to a given biomass feedstock. In our opinion, assignment of CO_2 uptake credits for annual crops, perennial grasses, and short-term-rotation trees is a reasonable assumption. The uptake credit for long-term forestry-derived feedstocks must be based on thorough, detailed analyses of the biomass harvest and growth cycle both with and without bioenergy production. We are currently undertaking such an analysis. If DeCicco believes that we have an “accounting error” (or, in our terms, “CO_2 omission”) for biomass combustion in GREET, he has simply missed the carbon accounting approach that we have built into GREET.

In summary, carbon uptake during biomass growth could offset the combustion emissions either completely or to a degree. The degree of offsetting depends on the growth cycle of given biomass types and detailed tracking of carbon sources for biofuel production. In fact, FCA is designed to track the carbon sources of a biofuel as well as CO_2 emissions from fossil energy use along the biofuel’s supply chain. DeCicco himself even acknowledged (p. 102) that “the carbon neutrality assumption is arithmetically correct within a biofuel lifecycle. It is also true globally if all biomass used in the world is the subject and terrestrial carbon stock impacts due to land-use change are accounted for separately.”

Biomass Additionality

The decision to assign a CO_2 uptake credit and to select its magnitude for bioenergy production is affected by the evaluation of biomass additionality for bioenergy. Biomass additionality expresses the idea that any bioenergy production should result in additional biomass growth in global terrestrial systems. Additional biomass growth is determined by economic conditions that help or hinder introduction of new technologies (such as better seeds and better farming practices, e.g., precision farming) and the biological potentials of ecosystems. That is, economics and biology are intertwined for addressing biomass additionality. Since 2008, many organizations, including Argonne, have been using economic models to address management of ecosystems and inter-relationships among different economic sectors and across different global regions both with and without bioenergy production. Also, economic drivers certainly affect biomass growth rates under these two scenarios. Elliott et al. (2014) demonstrated an example of how to evaluate this effect. DeCicco’s assertion that bioenergy production only results in one-to-one exchanges among different uses of biomass, without considering differences between natural and managed biomass growth, is erroneous.

Biomass additionality should be examined for different biomass feedstock types. We commend Searchinger and Heimlich (2015) for presenting six individual bioenergy cases to identify those that could result in GHG reductions. DeCicco did not offer this type of analysis in his paper.

In the context of biomass additionality, we offer the corn ethanol example. U.S. corn ethanol production has increased from 1.6 billion gallons in 2000 to 14.3 billion gallons in 2014 (RFA 2015). One would assume that this dramatic increase has resulted in additional corn production (together with production of the stalks and leaves known as corn stover), as compared to a counterfactual scenario without any corn ethanol production. That is, because of corn ethanol production, corn production has increased, resulting in the production of more biomass both in the grain that is actually converted to ethanol and animal feed and in the corn stover (see Mumm et al. [2014] for a detailed analysis). In other words, if we did not experience a corn price increase from below $2 a bushel to $4–7 a bushel in the past 15 years, we could not imagine the corn yield increase that the U.S. experienced in the same period. Growth in U.S. corn production has indeed come from intensification (e.g., intensive farming with advanced technologies) and extensification (i.e., additional corn farming acreage). While intensification should result in additional corn production together with additional stover production, the extent of additional biomass production due to extensification (switching from other crops and vegetation types to corn) requires modeling of different crop systems and other vegetation systems. A simplistic presumption that the carbon in corn ethanol is already sequestered in corn is not logical. Farmers grow corn for economic reasons; conversion of corn to ethanol is based on economics. Conversely, if corn prices drop to a very low level (say, below $2 per bushel), farmers will not grow ***additional*** amounts of corn through a variety of means, including advanced technologies, since such behavior would not make economic sense. Again, this observation demonstrates the need to assess biomass additionality in both economic and biological contexts.

A key difference between biomass carbon and fossil fuel carbon is in the respective carbon cycles. Fossil fuel carbon comes from the underground fossil carbon stock created a few million years ago. In his proposed analytic framework, DeCicco did not take into account the avoided CO_2 emissions from the fossil energy displaced by bioenergy, even though he casually pointed out the avoided fossil CO_2 emissions in his discussion. Biofuels from additional biomass are introduced to displace fossil fuels. Thus, biomass additionality for biofuels should be examined ***together*** with the ***fossil energy subtractionality*** that is caused by biofuels.

On the other hand, biomass carbon derives from biogenic carbon stock and carbon flow via biomass growth. If biogenic carbon stock (both above- and below-ground) is tapped for bioenergy production, the time required for re-establishment of biomass carbon stock by biomass growth can affect bioenergy's carbon reduction significantly. But if bioenergy carbon comes from the annual carbon flow of biomass growth, bioenergy should offer GHG reductions. In practice, biomass is the currency for growers. The long-term economic viability of their business lies in sustaining biomass growth for harvest instead of depleting biomass carbon stock. That is, considerations of long-term economic viability should encourage growers to produce bioenergy from the carbon flow, not from permanent carbon stocks. Private forest management in the U.S.

offers a good example of the practice of biomass harvest from biomass flow, not stock, even though the biomass flow via forest growth could be subject to a 20- to 50-year time horizon. Of course, this time horizon is much shorter than the fossil carbon cycle.

In addition to the biomass additionality concept, DeCicco particularly questioned whether the carbon flow of ecosystems would be changed as a result of biofuel production. His question can only be answered by scientifically addressing the two key issues below:

- Would farmers/growers continue to grow biomass if there were no demand for biomass due to bioenergy production? In particular, if there were no cellulosic biofuel industry demanding cellulosic biomass, can one assume that farmers/growers would grow cellulosic biomass anyway?
- When bioenergy production results in managed biomass growth, how does the growth rate differ from that of natural biomass growth?

Biomass Additionality versus Consequential Life Cycle Analysis

Compared to the biomass additionality concept, the consequential LCA approach calls for estimating the consequences of biofuels technologies or policies (Earles and Halog 2011; Ekvall and Weidema 2004). Both the biomass additionality and the consequential LCA approaches imply a “with-without” comparison, but the implementation of each approach is quite different.

The additional biomass assumption is well expressed by Searchinger and Heimlich (2015): “The world’s lands are already growing plants every year and these plants are already being used” (p. 16). In other words, the assumption is that every hectare of land that goes to biofuels is deducted from other uses. Another related argument often embedded in the biomass additionality concept is that it would be better to use any available land to sequester carbon than to produce biofuels to displace fossil carbon. In addition, the food-fuel argument is often commingled with the biomass additionality concept (Searchinger and Heimlich 2015). There have been several studies that compare forest sequestration with biofuels and biopower (e.g., Mccarl 2007). Some use a carbon tax, with endogenous decisions on the amount of sequestration and biofuels that will be produced over a range of carbon prices (Suttles et al. 2014). The biomass additionality argument makes the assumption that all land is being used, that any plant material use for biofuels necessarily means less availability elsewhere, and that sequestration is more efficient than biofuels production. None of these assumptions are adequately justified by their proponents. In fact, some studies (e.g., Cai et al. 2010) find notable amounts of marginal, underutilized lands that could be converted to biomass production, ostensibly increasing their carbon content.

The consequential LCA approach normally uses as its system boundary the entire domain of any given policy (Taheripour and Tyner 2014). By default, the approach does indeed address biomass additionality. The consequential LCA approach normally makes use of CGE models to estimate the impacts of what are called market-mediated responses to the higher demand from biofuels (Hertel and Tyner 2013). Possible responses included the following:

- With a higher price, consumption (quantity demanded) would normally fall.
- With a higher price for a given commodity, there can be switching among crops to produce more of one crop and less of others.
- With a higher demand for a given commodity for biofuels, more cropland may be needed to meet that increased demand, and this cropland can come from conversion of pasture or forest. This is referred to as a change on the extensive margin.
- With a higher demand for a given commodity, the existing cropland might be farmed more intensively such as via double-cropping or irrigation or other investments in increased productivity and yield. This is referred to as a change in the intensive margin. An increase in intensive margin on existing cropland reduces demand for land conversion (from either forest or pasture to cropland).
- With a higher demand for a given commodity, there can be impacts on international trade of the commodity and of substitute commodities. In other words, a biofuel demand increase in one country can have repercussions anywhere in the world because the agricultural commodity markets are global.

It is important to note that many CGE models take into account limits on conversion of forests, high-carbon stock lands that merit protection, such as are contained within the renewable fuel standard (RFS). In its implementation of the RFS, the USEPA requires that the land used to produce biofuel feedstocks had been managed, fallow, and *non-forested* as of December 19, 2007. Furthermore, the USEPA checks the total area of agricultural land in the U.S. against the 2007 baseline of 402 million eligible crop-acres to assess whether agricultural land is increasing. If it is, biofuel producers must show that the land from which feedstock is produced was cleared or cultivated prior to December 19, 2007.

An important difference between the consequential LCA approach and the biomass additionality approach is that the former is driven by market forces to determine additional biomass production, whereas the latter simply assumes that any incremental demand reduces availability elsewhere. Biomass production is driven by market forces, and there is no simple one-for-one replacement among all uses of biomass as biofuels production increases.

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